Scientific Journal of Astana IT University
ISSN (P): 2707-9031 ISSN (E): 2707-904X
VOLUME 23, SEPTEMBER 2025

DOI: 10.37943/23GDLZ8527

Baisultanbekmyrzakhan Akbarov
Master's degree student; Department of Radio Engineering Electronics and Telecommunications
baisultan.akbarov@mail.ru, orcid.org/0009-0004-1819-5480
L.N. Gumilyov Eurasian National University, Kazakhstan

Kanat Makhanov
Candidate of Physical and Mathematical Sciences, Senior Lecturer, Department of Radio Engineering Electronics and Telecommunications
makanov@inbox.ru, orcid.org/0000-0002-1263-0734
L.N. Gumilyov Eurasian National University, Kazakhstan

Ilmira Kanymgaziyeva
Candidate of Physical and Mathematical Sciences, Department of Radio Engineering, Electronics and Telecommunications
Ilmira_69@mail.ru, orcid.org/0000-0001-6444-8988
L.N. Gumilyov Eurasian National University, Kazakhstan

Temirlan Imanbayev
Master's degree student; Department of Radio Engineering Electronics and Telecommunications
timarealtalk@gmail.com, orcid.org/0009-0002-4335-3925
L.N. Gumilyov Eurasian National University, Kazakhstan

Nurbek Abeuov
Master's degree student; Department of Radio Engineering Electronics and Telecommunications
nurbeea@gmail.com, orcid.org/0009-0005-8367-8750
L.N. Gumilyov Eurasian National University, Kazakhstan

Chingiz Dissyukov
Master's degree student; Department of Radio Engineering Electronics and Telecommunications
chingiz_kz_1@mail.ru, orcid.org/0009-0001-4832-4317
L.N. Gumilyov Eurasian National University, Kazakhstan

DESIGN AND DEVELOPMENT OF CIRCULARLY POLARISED ANTENNA FOR RFID SYSTEM

Abstract: This paper presents the research and development results of circularly polarised antennas used in radio frequency identification (RFID) systems. Such antennas play a crucial role in improving reliability, orientation independence and reading range of RFID systems in industry, transport and logistics. The frequency range under consideration is 860-900 MHz (UHF), which is widely used for passive RFID technologies due to its favorable propagation characteristics and compatibility with international standards. A printed antenna from FEIG ELECTRONIC GmbH (Germany) was used as a reference for the developed antenna. This paper presents the results of a similar antenna but without the use of a symmetry transformer. The elimination of this component reduces the overall design complexity, improves manufacturability and minimizes manufacturing cost, making the design more suitable for mass deployment. The printed dipole was developed on a 1.6 mm thick FR4 substrate with a relative die-

Received: 05.03.2025 Accepted: 24.09.2025 Published: 30.09.2025

lectric constant of 4.3 and a dielectric loss tangent of 0.02. The dimensions of the developed printed dipole correspond to 332 mm × 34 mm × 1.6 mm. The printed dipole and the overall design of the developed RFID antenna were pre-simulated in the software environment "CST Studio Suite", which allows accurate simulation of the electromagnetic behavior. This modelling step was necessary to optimize the input matching, radiation efficiency and circular polarization characteristics. The frequency of the designed antenna was 868 MHz (|S11| < -10 dB). and the radiated power was measured to be -11.7 dBm. The layout of the printed dipole was designed using Altium Designer software. The prototype assembly proceeded following model-based and electromagnetic simulation techniques. A Spectrum Rider FPH spectrum analyzer conducted test measurements which supported the theoretical prediction results. The proposed framework demonstrates great promise as an inexpensive solution with high detection efficiency for modern RFID systems operating in diverse conditions.

Keywords: Antenna; circular polarisation; radio frequency identification (RFID); reader antenna; Ultra High Frequency (UHF).

Introduction

Radio Frequency Identification (RFID) operates as a wireless identification method which depends on electromagnetic fields or radio waves to identify labeled objects without active mechanisms [1]. During recent years this developing technology has emerged in numerous applications affecting daily human activities. The RFID system that operates on the UHF band receives widespread interest due to its multiple applications including maintenance procedures and electronic toll collection and merchandise management [2]. UHF Band Technology offers wide read ranges as well as efficient data transfer capability [3]. The fundamental elements for an RFID system include a tag and a reader under the control of microprocessor or digital signal processor oversight [4]. UHF RFID operates within different wavelengths throughout the world at 840.5-844.5 and 920.5-924.5 MHz in China, 866-869 MHz in Europe, 902-928 MHz in North and South America, 952-955 MHz in Japan, 920-926 MHz in Australia, 865-867 MHz in India, 908.5 - 914 MHz in Korea. The list contains extra frequencies together with [5] and [6]. The document [7] presents supplementary frequency information together with regional specifications and specific exceptions.

The UHF band exists within the frequency area extending from 300 MHz to 1 GHz. UHF RFID operates within the entire frequency band spanning from 840 to 960 MHz. It would benefit RFID systems by improving the configuration process and decreasing overall costs if a single antenna with worldwide frequency capability existed. Multiple antenna systems as well as reader devices have been created using diverse structural methods. Several designs incorporate microstrip elements which contain built-in slots as key components according to [8], [9], [10]. The implementation of liquid dielectric materials in patch antennas enhances performance characteristics as mentioned in [11]. Various integrated antenna readers were both proposed and implemented according to research [12], [13]. The signal in circular polarisation travels through vertical and horizontal planes with a rotational phase shift of 90 degrees. Any antenna employing vertical or horizontal polarisation can be substituted by one using circular polarisation guidelines. An antenna with linear polarisation cannot detect RFID signals from any tag orientation whereas its reverse is not possible since linear antennas work only for specific signal orientation angles [14], [15].

Several research studies have focused on circularly polarised antennas with different approaches explored for producing circularly polarised radiation [16], [17]. The design process for circular polarisation antennas with special geometries appears in [18] and [19]. This paper investigates asymmetric structures for creating circular polarised radiation according to [20]. FEIG ELECTRONIC GmbH [21], [22] introduced patch antennas that included symmetric match-

Scientific Journal of Astana IT University
ISSN (P): 2707-9031 ISSN (E): 2707-904X
VOLUME 23, SEPTEMBER 2025

ing transformers to boost impedance matching performance. The complexity along with higher manufacturing costs endures from this antenna design strategy. A key challenge exists to develop antennas which should maintain simple design without matching transformers while maintaining reliable operation in the 868-900 MHz spectrum. Previous analysis suggests that antenna development with control features and affordable cost remains a viable task despite existing ready-made solutions and numerous antenna designs. The antenna needs to ensure dependable communication across all labeling orientations and function between 868-900 MHz while maintaining a basic design format that avoids complex matching transformers. The simplified fabrication steps together with decreased manufacturing expenses will result from this modification. This document aims to create a circular polarization antenna design without needing embedded matching transformers. An antenna dipole forms the main subject of research for its operation across 868-900 MHz frequencies.

Methods and Materials

The development process incorporated antenna theory analysis and synthesis methods. Standard formulas within the software environment "CST Studio Suite" allowed calculations and modeling to proceed. Experimental measurements for evaluating the developed antenna characteristics took place at the last development phase.

Our study began with analyzing the antenna design from reference [23], [24]. The antenna includes two radiating elements which make up its dipole design. The antenna demonstrates performance at a load resistance of 50 ohms according to initial measurement results. The determined standing wave coefficient ($\mathrm{VSWR} = 1.13$) revealed that the antenna reached its maximum at 868 MHz while operating at a dipole width of $\mathrm{w} = 3$ mm. The resistor between dual dipoles carries a resistance value of 1 MOhm. The dielectric constant used for the FR4 material board amounts to $\mathrm{er} = 4.3$ while its dielectric height stands at $\mathrm{h} = 1.6$ mm and its copper track thickness reaches $\mathrm{t} = 0.035$ mm. The parameters for designing the modernised antenna have been established as preliminary design guidelines. The planned device for matching transformer and resistor is a self-contained circuit board functioning as a dipole. The developed printed dipole (PD) appears as presented in Figure 1. The antenna lengths and widths are illustrated through sections a and b that need model-based measurements to determine them.

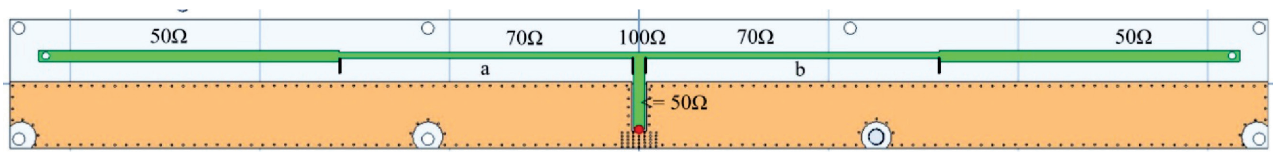

Figure 1: Printed dipole of the developed antenna

As can be seen from this figure, the lengths of sections a and b are $\frac{\pi}{4}$ of the operating wavelength. Since the antenna is designed for use in the 868 MHz band, it follows that the length of the dipole is ~ 314 mm. Accordingly, the equality condition is the ratio:

$$a = b = \frac{\lambda}{4} \tag{1}$$

It follows that:

$$a = b = \frac{314}{4} = 78.5\, mm$$

Using the formula for translating the wave impedance, for sections a and b we find the required value of resistance for dipoles:

$$R = \sqrt{R_1 * R_2} \qquad R = \sqrt{50 * 100} = 70\ \Omega \tag{2}$$

Thus, we have found that to obtain a 50-ohm matching transformer, the impedance of sections a and b must be equal to 70 Ohms. If we design two 70 Ohm dipoles, the physical realisation of these dipoles with the calculated width, will give us two 100 Ohm dipoles. Two 100 Ohm dipoles connected in series at the junction will give us the 50 Ohms we need. Based on these considerations, in the modelling environment we have calculated the widths of sections *a* and *b* using the formula:

$$Z_0 = \frac{87}{\sqrt{\varepsilon_r + 1.41}} ln\left(\frac{5.98 \times h}{0.8 \times w + t}\right) \tag{3}$$

Here:

e_r – the dielectric constant of the material.

w – width of the copper track.

t – thickness of the track.

h – height of the dielectric substrate.

Z_0 – wave impedance of sections a and b in ohms.

All the above parameters were set in advance. Only the width of the copper track (w), acting as a PD, remained unknown. It was necessary to choose such a value of width that its wave impedance at the known length was 70 Ohms.

$$Z_0 = \frac{87}{\sqrt{4.3 + 1.41}} ln\left(\frac{5.98 \times 1.6}{0.8 \times 1{,}67 + 0.035}\right) \approx 70\ \Omega \tag{4}$$

By selecting the required value in formula (4), the required track width was calculated. It follows that at a width of ≈ 1.67 mm, the wave impedance of dipoles will correspond to 70 Ohm.

Thus, at this stage of the study, we have established the basic geometric dimensions of the PD. For effective line matching, it is necessary to design a dipole with sections *a* and *b*, which have width and length to correspond to $w = 1.67$ and $a = b = 78.5$ mm.

Figure 2 shows the results of modelling the S11 parameter of the designed printed dipole. Figure 3 shows the results of modelling the VSWR of the designed printed dipole.

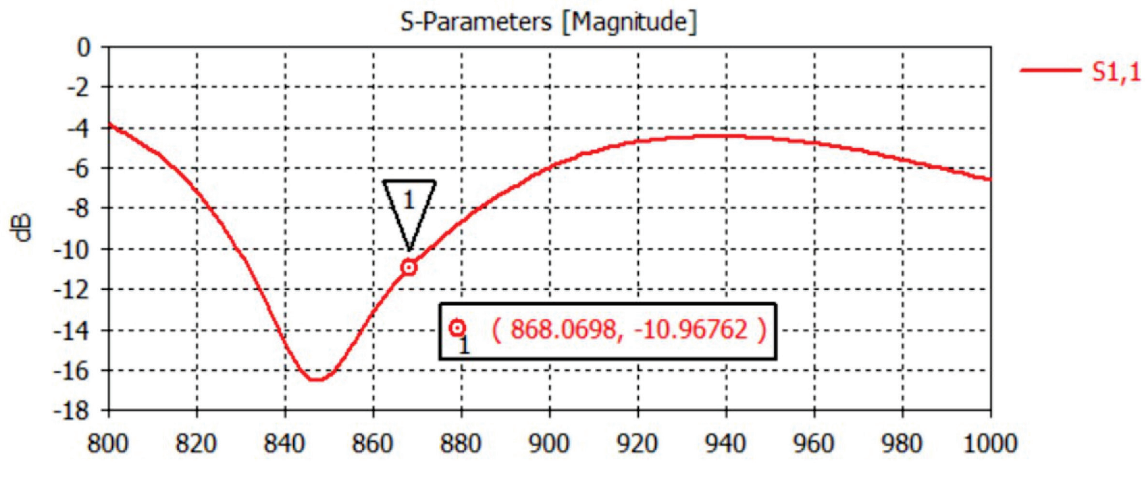

Figure 2. Simulation results of the printed dipole at 868 MHz (S11 parameter)

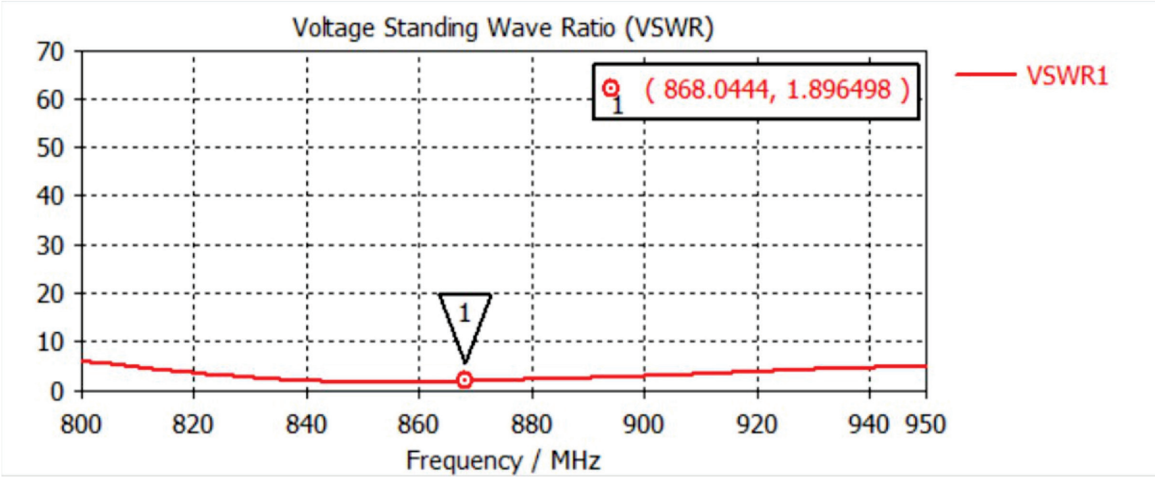

Figure 3. Simulation results of the printed dipole at 868 MHz (VSWR)

Also, the simulation results allowed us to calculate the values of return loss and VSWR. It is found that the return loss does not exceed 10 dB in the frequency range of 840-869 MHz. The VSWR of the modelled antenna at 868 MHz was 1.89, which is in good agreement with the original parameters.

A depiction of the antenna radiation patterns at 868 MHz can be found in image 4 while showing two perpendicular $\varphi = 90°$ and $\varphi = 0°$ measurements. The antenna achieved symmetrical radiation patterns together with wide-angle AR characteristics during the $\varphi = 90°$ measurement in both planes. The antenna displays a 66-degree 3dB beamwidth that makes it appropriate for wideband RFID implementations. At 868 MHz the main radiation lobe delivers a gain between 12 to 13 dBi. The level of the side lobes = -15.3 dB. In the second figure at $\varphi = 0°$. The beam width attains -3 dB of level in the plane $\varphi = 90°$ which spans 60-70° and the plane $\varphi = 0°$ where it reaches 25-30°. Figure 4 represents the three-dimensional antenna pattern while observing at a $\varphi = 0°$ angle.

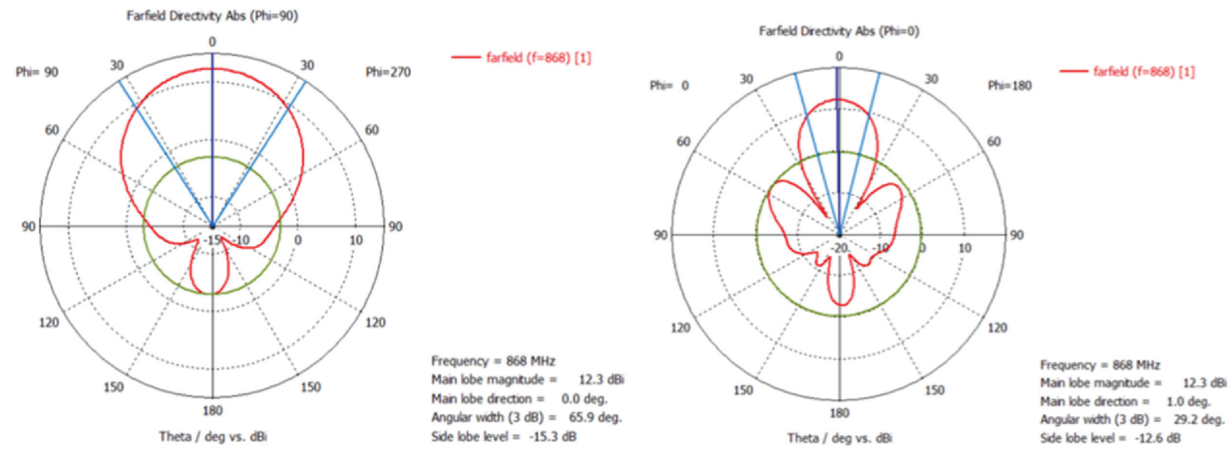

Figure 4. Directional diagram at $\varphi = 90°$ and $\varphi = 0$

The designed antenna at 868 MHz demonstrates its three-dimensional far-field radiation pattern as shown in Figure 5. The antenna diagram clearly demonstrates that its main lobe points directly towards the positive Z-axis which indicates effective boresight directivity. The antenna effectively directs radiation power through its 12.28 dBi maximum directivity capability. The color scale of the surface depicts the power distribution in space through its transition from red to blue regions which shows increased and decreased radiation intensities, respectively.

Visual assessment shows the radiation pattern spreads symmetrically while producing multiple secondary lobes at off-axis positions and attains a side lobe level of -15 dB. The antenna maintains a total efficiency of -1.386 dB which represents 73% of full power potential along with a radiation efficiency of -0.949 dB or 80% efficiency marking minimal power loss in the device. The antenna provides suitable performance for RFID systems which require medium operating range and high directivity coupled with efficient transmission.

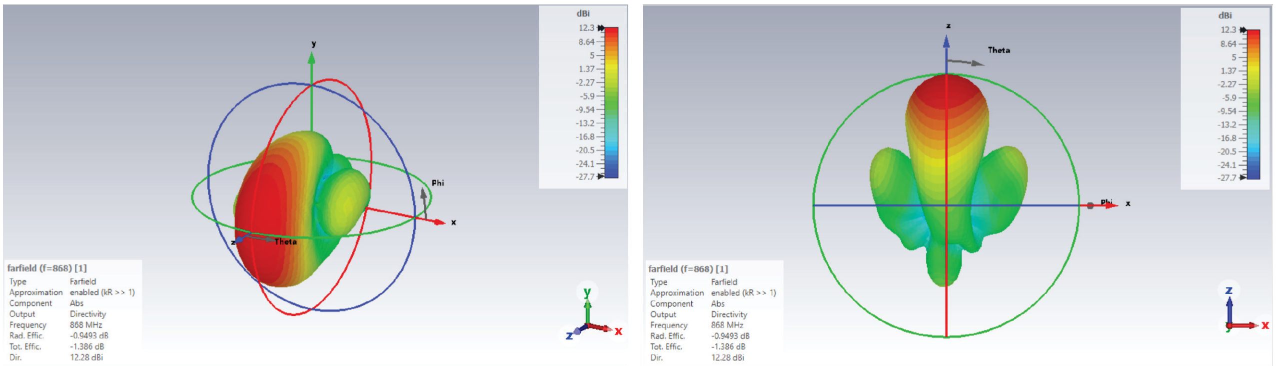

Figure 5. 3D Directional diagram

Results and Discussion

In the next step, the work related to the design of the PD board and direct assembly of the antenna prototype was realised.

The design and tracing of the PD board was carried out in Altium Designer environment [25]. The dimensions of the PD board correspond to: 332 mm*34 mm*1.6 mm. The appearance of the designed PD board is shown in Figure 6.

The printed version of the dipole was based on the parameters that were obtained from the results of modelling.

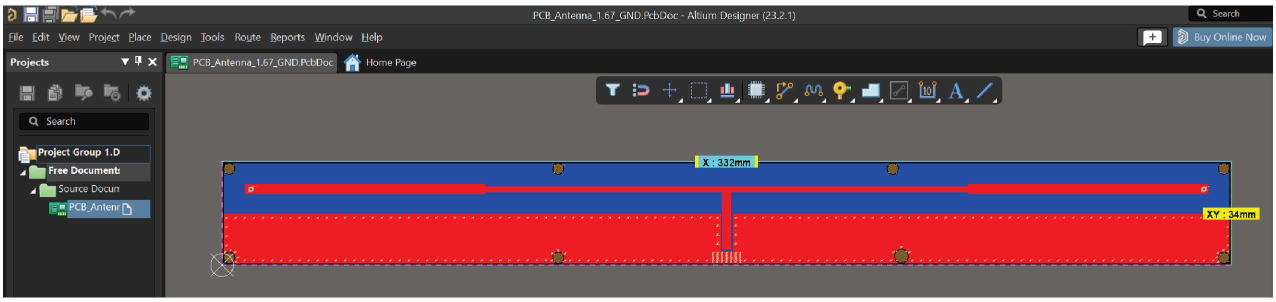

Figure 6. Appearance of the printed dipole designed in Altium Designer environment

As soon as the printed dipole was made, we started to realise the next stage - the development of the antenna design with subsequent assembly.

Preliminary, in the environment 'CST studio Suite' was carried out work on modelling the appearance and complete design of the antenna. On the basis of the results of modelling were prepared component parts of the antenna: two radiators, reflector and coaxial cable for power input. The dimensions of the brass radiators corresponded to 157*157 mm. To form the elec-

Scientific Journal of Astana IT University
ISSN (P): 2707-9031 ISSN (E): 2707-904X
VOLUME 23, SEPTEMBER 2025

tromagnetic field of circular polarisation, the edges of the radiators were truncated by $\Delta L=24.5$ mm. A sheet of duraluminium was used as a reflector. The printed dipole was pre-fixed to the duralumin reflector. Two brass radiators were mounted and fixed to the surface of the reflector. The mounting height of the radiators relative to the printed dipole was 14 mm. The electrical feed of the antenna was connected by means of a coaxial cable using an SMA connector.

The external view of the assembled antenna from the front and rear fronts is shown in Figure 7.

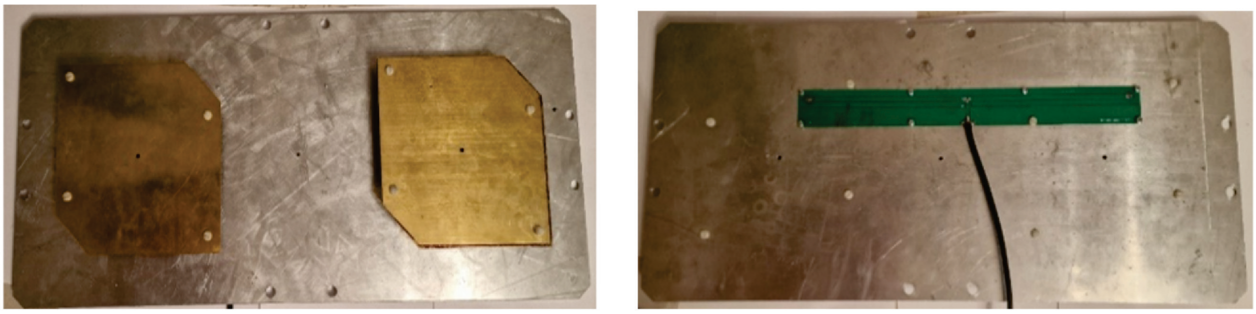

Figure 7. Appearance of the designed antenna assembly

At the next stage of the realised tasks, experimental measurements of the radiophysical parameters of the antenna were carried out. The purpose of these measurements was to check the compliance of the real parameters with the required characteristics.

First of all, experiments on registration of electromagnetic oscillation energy distribution in the antenna frequency band were carried out. Then, Spectrum Rider FPH spectrum analyser was used to implement these measurements. After that, registration of the electromagnetic wave radiated by the antenna was carried out at different distances: 2, 4, 6 and 8 metres. Along with the registration of the maximum frequency, the power level of the electromagnetic radiation was recorded.

The results presented in Figure 8 show that the maximum frequency of radiation corresponds to the specified range of 868 MHz. At the same time, the maximum power recorded at a distance of 6 metres from the front plane of the antenna is -11.7 dBm.

DOI: 10.37943/23GDLZ8527

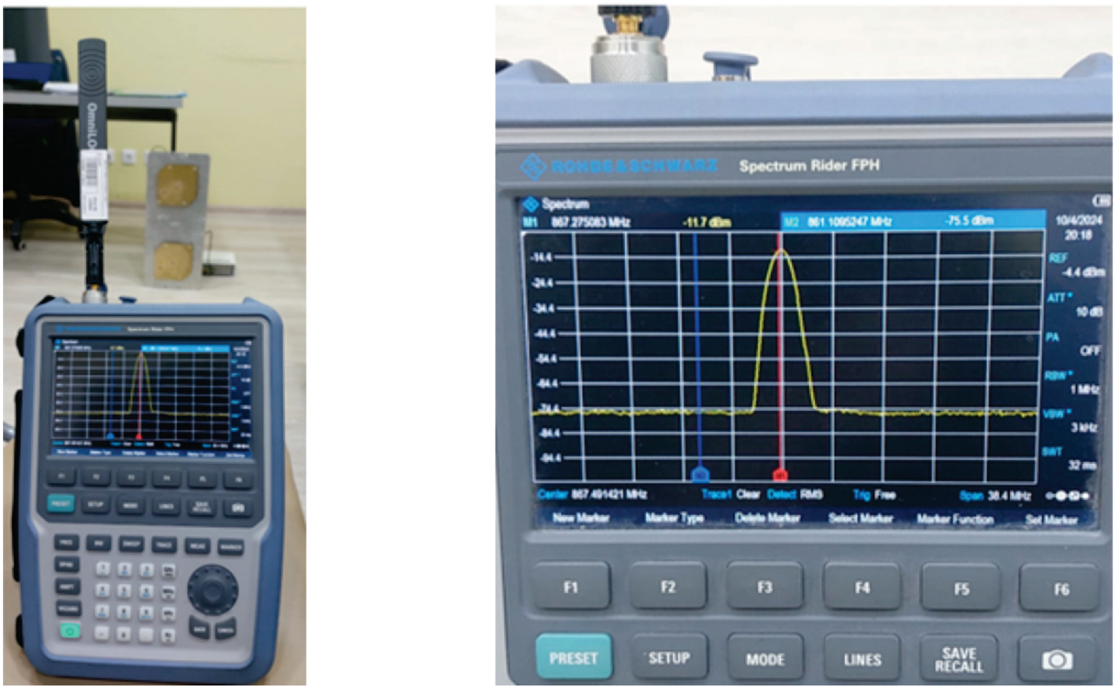

Figure 8. Stages of experimental measurements of radiophysical parameters

Table 1. Comparative Analysis of Industrial and Developed Antenna Parameters

Parameter	FEIG ID ISC.ANT.U600/270-EU	Developed Antenna (Without Transformer)
Operating frequency range, MHz	865–870	865–870
Gain, dBi	11.0	12.3
VSWR	< 1.3	< 1.3
Polarization	Circular	Circular
S11, dB	< -10	< -11
Connector type	SMA (50 Ω)	SMA (50 Ω)
Matching transformer required	Yes (balun)	No
Approximate manufacturing cost	High (complex, heavy housing)	~30% lower (simplified PCB)

The results of the comparative analysis presented in Table 1 indicate that the developed antenna produced by PCB technology and lacking a matching transformer has all the main electrical parameters of the industrial antenna FEIG ID ISC.ANT.U600/270-EU. Markedly, the designed structure has a slightly increased gain (12.3 dBi compared to 11.0 dBi of the industrial reference), whereas VSWR, as well as the 3 dB beamwidth, are within conventional ranges guaranteeing safe use even at medium range of RFID applications.

It was shown that the optimal dipole structure could enable efficient matching by experimental measurements and full-wave electromagnetic simulations.

The resonant frequency of the designed antenna is measured to be at 865MHz which lies within the desired RFID band (865-868 MHz) and the reflection coefficient S11 is measured to be less than -10 dB indicating that there are no additional impedance matching circuits needed.

These findings support the engineering practicability of the suggested design alternative: simplified construction will not rather undermine the antenna functionality, but quite the other way round, it will enhance manufacturability, and it will decrease the cost of manufacturing.

This makes the design very suitable for mass applications in industrial and logistics RFID systems where cost-effectiveness, reliability and ease of integration are critical factors.

Conclusion

In the course of the work performed, a circularly polarised antenna has been fully developed, designed, assembled and tested. By analysing the test results, it can be stated that the parameters of the developed printed dipole correspond to the required values.

By selecting the desired value, the width of the printed dipole was calculated, at which its wave impedance agreed with the wave impedance of the load.

The results of the modelling allowed to pre-determine both the dimensions of the printed dipole and, in general, the design of the antenna as a whole.

Experiments on studying the real values of radio-physical parameters of the antenna showed full compliance of the maximum frequency and radiation power with the expected ones.

The obtained results create a basis for further development of reading systems based on this antenna, which will increase its functionality and expand the application areas of RFID-technologies.

References

[1] Juels A (2006) RFID security and privacy: A research survey. IEEE J. Select. Ar. Comm. 24(2): 381–394. https://www.acsu.buffalo.edu/~mblanton/cse708/rfid-survey.pdf

[2] Y. Álvarez López, J. Franssen, G. Álvarez Narciandi, J. Pagnozzi, I. González-Pinto Arrillaga, F. Las-Heras Andrés (2018). RFID technology for management and tracking: E-health applications. Sensors, 18 (8), p.2663. https://doi.org/10.1016/j.ptlrs.2025.05.001

[3] Chen, Z. N., Qing, X., & Chung, H. L. (2009). A universal UHF RFID reader antenna. IEEE Transactions on Microwave Theory and Techniques, 57, 1275–1282. https://doi.org/10.1109/TMTT.2009.2017290

[4] H.L. Chung, X. Qing, and Z. N. Chen. (2007). A broadband circularly polarized stacked probe-fed patch antenna for UHF RFID applications. Int. J. Antennas Propag., vol. 2007, Art. ID 76793, 8 pp. https://onlinelibrary.wiley.com/doi/epdf/10.1155/2007/76793

[5] L. Jeremy. (2005). The History of RFID. IEEE Proceedings, vol. 24, №4, pp. 8–11. https://doi.org/10.1109/MP.2005.1549751

[6] K. Finkenzeller. (2003). RFID Handbook. John Wiley & Sons, New York, NY, USA, 1st ed. p. 427.

[7] H.W. Kwa, X. Qing, and Z. N. Chen. (2008). Broadband single-fed single-patch circularly polarized antenna for UHF RFID applications. in IEEE AP-S Int. Antennas Propag. Symp., San Diego, CA, Jul. 5–11., pp. 1072–1075. DOI:10.1109/APS.2008.4619871

[8] El Ahmar, L., Errkik, A., Zbitou, J., Bouzida, I., Oukaira, A., & Lakhssassi, A. (2024). Novel printed passive ultra-high-frequency radio frequency identification antenna using meander technique. *Indonesian Journal of Electrical Engineering and Computer Science, 33*, 1474–1485. https://doi.org/10.11591/ijeecs.v33.i3

[9] Wang, B. (2015). A compact antenna design for UHF RFID applications. *Progress in Electromagnetics Research Letters, 53*, 83–88.

[10] Chen, Z., Li, H.-Z., Wong, H., Zhang, X., & Yuan, T. (2021). A circularly-polarized-reconfigurable patch antenna with liquid dielectric. *IEEE Open Journal of Antennas and Propagation, 2*, 396–401. https://doi.org/10.1109/OJAP.2021.3064996

[11] Tajin, M. A. S., & Dandekar, K. R. (2020). Pattern reconfigurable UHF RFID reader antenna array. *IEEE Access, 8*, 187365–187372. https://doi.org/10.1109/ACCESS.2020.3031296

[12] Parthiban, P. (2019). Fixed UHF RFID reader antenna design for practical applications: A guide for antenna engineers with examples. *IEEE Journal of Radio Frequency Identification, 3,* 191–204.
[13] Zhang, J., & Shen, Z. (2017). Compact and high-gain UHF/UWB RFID reader antenna. *IEEE Transactions on Antennas and Propagation, 65*, 5002–5010
[14] Patch antenna krugovoj poljarizacii. Retrieved from: https://3g-aerial.biz/
[15] Ibrahiem, A., Vuong, T.-P., Ghiotto, A., & Tedjini, S. (2006). New design antenna for RFID UHF tags. In Proceedings of the IEEE Antennas and Propagation Society International Symposium (pp. 1355–1358). https://doi.org/10.1109/APS.2006.1710797
[16] Pan, C.-L., Wang, S. T., Chen, P.-C., & Chen, Y.-F. (2023). Design of 2.45GHz circularly polarized tag antenna. Journal of Communications, 18, 608–612.
[17] Norzeli, S. M., Ismail, I., & Busu, M. F. M. (2012). Designing a UHF RFID reader antenna. In *Proceedings of the IEEE Symposium on Humanities, Science and Engineering Research* (pp. 599–602).
[18] Liu, Q., Shen, J., Liu, H., Wu, Y., Su, M., & Liu, Y. (2015). Low-cost compact circularly polarized directional antenna for universal UHF RFID handheld reader applications. *IEEE Antennas and Wireless Propagation Letters*, 14, 1326–1329.
[19] Moharana, M., & Dwivedy, B. (2024). Circularly polarized planar antennas with enhanced characteristics. *IEEE Access, 12*, 134594–134613. https://doi.org/10.1109/ACCESS.2024.3415483
[20] Wu, S., Yuan, J., Chen, J., & Li, Y. (2020). Compact circularly polarized microstrip ring antenna using capacitive coupling structure for RFID readers. *IEEE Access, 8*, 32617–32623. https://doi.org/10.1109/ACCESS.2020.2973719
[21] Cao, R., & Yu, S.-C. (2015). Wideband compact CPW-fed circularly polarized antenna for universal UHF RFID reader. *IEEE Transactions on Antennas and Propagation, 63*, 4148–4151.
[22] Liu, X., Liu, Y., & Tentzeris, M. M. (2015). A novel circularly polarized antenna with coin-shaped patches and a ring-shaped strip for worldwide UHF RFID applications. *IEEE Antennas and Wireless Propagation Letters, 14,* 707–710.
[23] Li, J., Liu, H., Zhang, S., Luo, M., Zhang, Y., & He, S. (2018). A wideband single-fed, circularly-polarized patch antenna with enhanced axial ratio bandwidth for UHF RFID reader applications. *IEEE Access, 6*, 55883–55892.
[24] FEIG ELECTRONIC GmbH. (2025). ID ISC.ANT.U600/270-EU. Retrieved from https://www.feig.de
[25] Altium Designer. Retrieved from https://www.altium.com/altium-designer